Overview for Abalone Recovery and Management Plan Workshop on Management

March 15, 2002

1. Introduction

The Department of Fish and Game (Department) is mandated by the State legislature to prepare an Abalone Recovery and Management Plan (ARMP) for all California's abalones. An earlier workshop focused on the recovery portion of the ARMP. The purpose of this workshop is to elicit an independent review of concepts for the proposed management portion of the plan for the ongoing recreational red abalone (*Haliotis rufescens*) fishery north of San Francisco Bay. Eventually these same concepts will be applied to future recovered abalone stocks in the south. This overview describes three major management components: the status of the stocks, the proposed management plan, and future management strategies and refinements.

2. Status of Stocks and Management Considerations

Abalone stocks in California have been fished for 10,000 years, first by Native Americans and later by a diversity of people. A commercial fishery was established throughout southern and central California in 1909 but the expansion of the sea otter population in central California in the 1940's precluded a fishery in that area (Wendell 1994). The southern California fishery was closed in 1997 due to stock collapse. Red abalone is currently open for sport fishing in northern California from the Oregon border to San Francisco (Sec. 27.00, Title 14, CCR). The history of the rise and ultimate collapse of the southern California red abalone fishery provides an important context for proposed northern management and any potential future southern abalone fishery.

Northern and southern red abalone populations have followed divergent trends, largely due to the differing management strategies used in each region. In central and southern California, red abalone landings rapidly increased in the early 1940's and then gradually declined until 1951 when pink (*H. corrugata*) abalone entered the fishery. Peak red abalone landings were approximately 1,250 metric tons (2.5 million lbs) in 1967. Between 1967 and 1996, southern red abalone stocks experienced a long decline as the fishery collapsed to less than 200 metric tons (400,000 lbs) (Karpov et al. 2000). The commercial and recreational fishery in southern California was closed for all species in 1997 (section 5521 of the FGC).

2.1 Northern California Red Abalone

Northern California red abalone populations have supported a viable sport fishery to the present time, largely due to the prohibition of both commercial fishing and the use of SCUBA by sportsmen (Tegner et al. 1992; Karpov et al. 1998). Without SCUBA, most sportsmen can not reach abalone deeper than 8.4 m. This creates a refuge from fishing mortality for approximately 14% of the red abalone population.

The status of the northern red abalone fishery was analyzed in 2001. Four significant trends were revealed: 1) a concentration of fishery effort and increased take in Sonoma and Mendocino Counties during the past decade, 2) little evidence of sublegal and juvenile recruitment at both fished and reserve survey sites, 3) declines in deep water stocks at some sites, and 4) evidence of serial depletion.

2.1.1 Concentration of Fishery Effort and Increased Take

Average take and effort estimates for 1998 to 2000 have increased compared to estimates from 1983 to 1989, and there has been a substantial concentration of fishery effort in Sonoma and Mendocino Counties. These two counties accounted for over 96% of the effort between 1998 and 2000, up from an estimated 76% from 1986 to 1989 (CDFG 2001). This effort shift has been accompanied by an estimated 25% increase in take. When poaching estimates (an additional 12% or 217,000 lbs) are added to the total take for 2000, red abalone take in Mendocino and Sonoma Counties exceeds 2 million pounds, which was the average red abalone harvest in southern California prior to the fishery collapse. This level of fishing was unsustainable for red abalone in southern California (Karpov et al. 2000).

2.1.2 Fishery and Juvenile Recruitment

Recruitment is a broad term that includes settlement of young-of-the-year abalone (< 31 mm), growth into reproductive sizes that contribute to spawning populations (>50 mm) (Giorgio and De Martini 1977), and entry into the fishery at sport legal size (178 mm). Young-of-the-year settle into cracks and crevices and then emerge into open areas as they enter the reproductive population. Recruitment is necessary to ensure replacement of animals removed by the fishery. Recruitment of juvenile (< 30 mm) abalone is indicative of successful reproduction, while recruitment of high densities of emergent abalone (100 to 178 mm) is predictive of increases in fishable populations (Karpov et al. 1998).

Large numbers of cryptic (< 100 mm) and emergent abalone were last observed between 1986 and 1992 at Van Damme State Park (VDSP) in Mendocino County (Karpov et al. 1998). Since 1992, the abundance of abalone between 50 and 125 mm has declined substantially at VDSP (Karpov et al. 2001). Recent surveys at four other northern coastal sites (Point Cabrillo and Bodega Bay Marine Reserves, and Salt Point and Fort Ross State Parks; Figure 1), revealed few young-of-the-year and emergent recruits, with young-of-the-year least abundant in Sonoma County. This lack of sublegal animals implies poor recruitment over the last decade. Given the slow growth rates of abalone, a successful spawn in any year would not reach sport legal sizes (178 mm) for over a decade.

2.1.3 Declines in Deep Water Stocks

Declines in deep-water stocks are evident from a study of two sites over the 1986 to 2000 period. Abundances of red abalone at deep depths (> 8.5 m, or 28 ft) decreased significantly at both Van Damme State Park and Point Cabrillo Marine Reserve (Karpov et al. 2001). Decreases in deep stocks mean that the "refuge by depth" is not protecting as many abalone as in previous years, leaving the population vulnerable to over fishing.

2.1.4 Serial Depletion

Catch and effort data provide evidence for serial depletion by area at heavily fished sites, with increased take of abalone from deeper water and from more remote locations and a decline in the number of abalone taken per trip. At one heavily impacted location (Moat Creek in Sonoma County) the distance of travel from access points to take locations doubled for shore-pickers from the period from 1989 to 1994 and 1995 to 2000. From aerial survey, between 1975 and 1985, there has been a significant decline in the number of shore-pickers, with diving effort increasing significantly. This represents a shift from intertidal to subtidal fishing as near shore stocks were depleted.

2.2 Status of Rare Abalone

There are three rare species of abalones found in northern California: pinto (*H. kamtschatkana*), flat (*H. walallensis*), and black (*H. cracherodii*). Surveys of abalone populations in northern California (1999-2001) at five sites show that flat and pinto abalone occur at very low densities (<0.004 per m^2) and make up a tiny fraction (<0.5%) of the total population. Low abundances preclude any California fishery for these rare abalone in northern California and these species are not addressed under management in the ARMP.

2.3 Other Fishery Considerations

Other factors may affect the sustainability of this fishery including poaching, environmental conditions, disease, sea otters, and abalone life history.

The Department is concerned about illegal take of abalone. Recent Wildlife

Protection arrests of abalone poachers revealed sophisticated distribution systems to San Francisco and Asia. Poaching may have been a factor in population declines in deep water (Karpov et al. 2001).

Natural disturbances that reduce kelp resources adversely affect herbivores including red abalone. During El Niño periods, seawater temperature may exceed the thermal tolerance for vulnerable life stages of some important macroalgae such as *Macrocystis* and *Nereocystis*, and whole beds may disappear.

Disease is a potential source of concern on the north coast; a small number of red abalone at one site (VDSP) have tested positive for the rickettsial-like prokaryote causing withering syndrome, though none have shown symptoms of the disease.

Sport and commercial abalone fisheries are not sustainable in areas of established sea otter populations (Watson 2000; Wendell 1994). Range expansion of the sea otter needs to be tracked in northern California .

The natural history of red abalone (long life span, slow growth, and infrequent localized recruitment) makes abalone resources vulnerable to over fishing and area-specific depletion. Spawning success is known to be adversely affected by low abalone densities (Babcock and Keesing 1999). Since the probability that sperm and eggs will meet decreases with distance (the Allee effect), when populations drop below a minimum spawning density, population declines and local extinction can result despite the presence of actively spawning individuals (Allee 1931).

Both the life history characteristics of abalone and any potentially adverse condition must be considered in the management of abalone fisheries.

2.4 Recent Management Actions

The Fish and Game Commission, acting on the advice of the Department's recommendation to reduce take by 50%, recently implemented regulation changes that are projected to reduce take by 41% from 2000 levels (CDFG 2001). To achieve this reduction, the daily limit was reduced from 4 to 3 abalone and the annual limit from 100 to 24 abalone. These regulation changes result in a projected reduction of total catch to 430,000 abalone or 1,195,900 lbs, from the 2000 sport take level of 728,500 or 2,027,000 lbs (a level that was unsustainable in the southern California abalone fishery). The effects of these recent regulation changes will need to be closely monitored to ensure that the projected catch level is not exceeded with the lowered annual and daily limits and to assess the impacts of this fishery reduction on stocks.

3. Proposed Management Plan

The proposed management plan is precautionary because data is currently limited, and calls for an establishment of the total allowable catch (TAC) at the 2002 projected catch level of 430,000 abalone per year. Once this TAC has been set, a review of regulations and status of stocks will occur on a biannual basis to determine: 1) if the TAC is being met with existing sport regulations, and 2) if any alteration of the TAC is warranted based on established criteria for stock health. The proposed management plan also describes stock conditions warranting localized area closure (or reopening). All fishery management adjustments in the plan will occur through a set of management tools; adjustments in TAC will occur primarily through the use of daily and annual limits.

The proposed management plan is based on the best available data, which includes fisheries dependent and independent information as well as published research. A set of criteria are described that guide the management decision making process. These include recruitment, density, occurrence of adverse events, and catch-per-unit-effort / serial depletion. The target levels for criteria may change as better data becomes available through additional research and modeling (Section 4: Refinements of the Proposed Plan and Alternative Management Strategies).

3.1 Criteria

Criterion 1: Recruitment

Successful recruitment is demonstrated by the presence of multiple size classes with specified densities of small (< 31 mm) and intermediate animals (> 30 mm and < 178 mm). Two types of surveys can be used to assess densities of recruits: invasive and emergent. In invasive surveys, rocks are turned over and all cracks and crevices are searched in order to count all sizes of abalone. Emergent surveys target abalone that are exposed on the substrate (abalone >100 mm) (Tegner et al. 1989). The full range of recruitment is best determined from invasive surveys, but emergent surveys sample a much larger area.

Two alternative approaches, both based on Van Damme State Park (VDSP) data, could be used to determine if the recruitment criterion has been met, depending on whether invasive or emergent monitoring methods are used. VDSP is the only site where a time series of data was collected that spanned a period of good recruitment. The 1990 to 1992 VDSP recruitment produced a tripling of fishable populations, that has sustained the local resource for the last decade. Densities from this period are therefore used as the baseline for the recruitment criterion. The first alternative involves invasive survey methods. Minimum densities of 600 abalone per hectare (ha) for small abalone (< 30 mm) and 7,700 abalone per ha for intermediate sized abalone (> 30 mm and < 178 mm) (Karpov et al. 1998) would indicate successful recruitment. The second alternative involves emergent surveys and uses 1992 VDSP data. Under this alternative, a minimum density of 4,500 animals per hectare for emergent, sub-legal abalone (100-178 mm) would indicate successful recruitment.

Criterion 2: Density

In the proposed plan, the Department will use two density targets: minimum viable and sustainable fishery levels.

The sustainable level is based on estimated densities necessary for a healthy fishery. Until alternate methods are developed, densities from emergent surveys at index sites will be used as proxies for estimating the sustainable fishery density target for red abalone. Quantitative subtidal monitoring of abalone along the northern California coast is limited to a few high use index sites. Surveys conducted from 1999 to 2000 by the Department and University of California at Santa Cruz at three index sites are the best available data to characterize current densities of abalone at popular fishing sites (Table 2). Density data was examined both across all depths and at deep depths only (> 8.4 m); a separate evaluation of densities in deep depths allows assessment of refuge populations outside of fishing depths. In the 1999 to 2000 surveys, an average of 6,600 abalone per ha were found across all depths, while in deep (refuge) depths, abalone averaged 3,300 per ha. These average densities have not declined significantly since last surveyed in 1986 (Parker et al. 1988), and constitute our current best estimate for sustainable densities that can support the ongoing fishery.

If stocks fall below the minimum viable population level (MVP), they are at risk of collapse. The MVP for red abalone is based on two sources of information that includes minimum spawning densities determined by Shepherd and Brown (1993) for another species of abalone (*H. laevigata*) and declines of red abalone in southern California (Karpov et al. 1998). Shepherd and Brown (1993) found that recruitment started to decline when densities of *H. laevigata* fell below 3,000 abalone per ha, leading to the suggestion that this is a critical density level. Stocks collapsed when adult densities fell below 1,000 abalone per ha. Comparable densities appear critical for red abalone; on Santa Rosa Island in southern California, densities of under 1,000 abalone per ha were not sustainable and were soon followed by a collapse of the population (Karpov et al. 1998). Therefore, a reasonable precautionary MVP level for red abalone is estimated at 2,000 abalone per ha.

Criterion 3: Occurrence of Adverse Events

Adverse events that are considered in management decisions include: El Niño events, poaching, disease, and expansion of sea otter populations (Section 2.3: Status of the Stocks and Management Consideration).

El Niño events are considered a threat to the fishery when prolonged periods of elevated sea water temperature result in decreased kelp production and increased abalone mortality.

Poaching is considered a management concern when the Department's Wildlife Protection Unit determines that levels have markedly increased. Because poaching is very difficult to directly determine, any apparent increase in poaching is indicative of a much larger problem (Daniels and Floren 1998).

Disease outbreaks are defined as either minor or major. Minor disease outbreaks are of a similar magnitude to those encountered in red abalone at San Miguel Island in 1993, when an estimated < 5% of stock had symptoms of withering syndrome. A major disease outbreak is defined as disease related mortality of >20% of the population. Major disease outbreaks impacting black abalone were first noticed when large numbers of animals were seen dead or dying. Ultimately up to 95% of their populations died across virtually the entire population range. When a disease episode occurs, a fishery would be removing naturally disease resistant animals.

Establishment of sea otter populations in all or part of the fishery range warrants closure of that portion of the fishery.

Criterion 4: Catch-per-unit-effort and Serial Depletion

The final criterion is based on the success of fishermen, as determined in creel (fishery dependent) surveys. CPUE is most simply determined as abalone taken per day or per hour. A significant decrease in CPUE over a four year period will trigger a management action. Similarly, serial depletion over the same time frame as evidenced by a significant increase in distance traveled from access points to take locations will trigger a management action.

3.2 Determining Fishery Adjustments: TAC and Area Closures

Projected catch levels established by the Fish and Game Commission action in 2001 are estimated at 430,000 abalone (1,196,000 lbs) per year, based on an estimated reduction of 41% from the 2000 landing level of 728,000 abalone (2,027,000 lbs). Our plan proposes setting this catch as the TAC to conserve stocks from over fishing and to protect remaining populations. As described in this text, references to changes in the TAC are from this proposed base-line level.

Two decision tables have been developed to direct management decisions: one to allow for adjustments in the TAC based on average area-wide conditions, and another to provide for area-specific closure (or re-opening) based on local conditions in areas monitored in creel surveys. The four criteria described (recruitment, density at deep and all depths, prevalence of adverse conditions, and CPUE / serial depletion; Table 1) will be used as a foundation for decisions in these tables. The specific target levels for each criteria were determined using the best available data on the northern red abalone populations and data from published abalone research (Section 3.1: Criteria).

Area Wide TAC Determination

The TAC determination table (Table 3) will be used to adjust the TAC for the overall fishery based on changes in average conditions among all surveyed sites. The table describes the combination of criteria that will lead to each of five management actions: 1) increase the TAC, 2) maintain the proposed TAC (430,000 abalone per year), 3) reduce the TAC, 4) close the fishery, and 5) re-open a closed fishery. This table uses three criteria: recruitment, density, and occurrence of adverse events.

The existing TAC (430,000 abalone per year) will be maintained (Action 2, Table 3) as long as densities at the three index sites remain within 25% of the current levels at both deep and all depths (~ 3,300 and 6,600 abalone per ha respectively), and no adverse conditions have developed. This will apply regardless of the prevalence of recruitment because the TAC was established in a poor recruitment condition. Although the TAC will not be altered when the above set of criteria are met, regulation changes in daily, seasonal, and annual limits (Section 3.3: Management Measures) may be required to ensure that the TAC is not exceeded.

An increase in the TAC of up to 25% (Action 1, Table 3) will be warranted under three conditions: if 1) recruitment criteria are met (Criteria 1), 2) densities at deep and all depths increase from current levels by 25% (to >4,100 and >8,300 abalone per ha respectively), and 3) no adverse conditions have developed. Given the history of decline in abalone fisheries in northern and southern California, a TAC increase greater than 25% (above 430,000 abalone per year) is not considered sustainable. This effectively sets the maximum TAC at 538,000 abalone (1,445,800 lbs) per year.

A reduction in TAC will occur under two alternate combinations of criteria. The first combination involves recruitment and target densities. If densities decline by 25% from current levels in either deep (< 2,500 abalone per ha) or all depths (< 5,000 abalone per ha), and the recruitment criterion is not met, a reduction in TAC of 25% will occur. Similarly, if any of three adverse events occurs (El Niño, a significant increase in poaching, or a minor disease episode; Criteria 3), a 25% TAC reduction will occur regardless of density levels or recruitment. If conditions show continued density decline on subsequent biannual cycles (but have not reached the threshold for fishery closure), then additional 25% reductions in TAC will be implemented incrementally. If no additional change in density has occurred, no further reduction will be implemented. Conversely, if densities return to year 2000 levels, the currently proposed TAC (430,000) will be reinstated.

Fishery closure will occur when average densities at the three index sites fall below 3,000 abalone per ha or when one of two adverse events occurs: a major disease episode or an area wide reoccupation of sea otters (Criteria 3). The target density for fishery closure of 3,000 abalone per ha is based on the minimum viable population size of 2,000 abalone per ha (Criteria 2) with a 50% precautionary buffer. Populations below this level are at a high risk of collapse. Major disease episodes or area wide sea otter reoccupation combined with human take also represent a high risk to populations, and could lead to extirpation of stocks in the fishery area.

Reopening of fisheries that have been closed will be considered when stocks have rebuilt to current fishery (year 2000) levels at both deep and all depths (> 3,300 and >6,600 abalone per ha).

Localized Closure Determination

The localized closure table (Table 4) will be used to determine whether areas should be closed due to extremely low densities and whether previously closed, but recovered, areas should be re-opened. Three criteria are used in this decision table: density at deep and all depths, CPUE / serial depletion, and adverse events.

A significant reduction in CPUE or a significant increase in distance traveled from access points to take locations (Criteria 4) at any creel survey site will trigger a dive survey of that area to determine if densities are approaching minimal viable population.

If dive surveys at any site show densities below 2,500 abalone per ha (based on the minimum viable population size of 2,000 abalone per ha with a 25% precautionary buffer), or either of two adverse events occur (any disease episode or a local re-colonization of sea otters), that site and surrounding areas will be closed to fishing. When a local area is closed, the overall TAC for the fishery will be reduced based on the proportion of estimated effort at the closed area (from report card data) to prevent increased take in remaining open areas.

If future dive surveys at a closed area exceed current sustainable levels (> 3,300 abalone per ha at deep and > 6,600 abalone per ha at all depths) and no adverse events (Criteria 3) are occurring, re-opening of that area will be considered. However, no closed area will be re-opened unless the entire range of the fishery meets the minimum criteria for an allowable fishery (as established in Table 3).

3.3 Management Measures

A variety of management tools are currently in use to manage and regulate the recreational fishery for red abalone in northern California. These include: gear restrictions, size limits, daily and yearly bag limits, area closures, seasonal closures, as well as license and report card requirements. A brief description of each existing management measure follows.

Gear Restrictions

Two types of gear restrictions are currently used in the abalone fishery: air supply and take tools. The prohibition of the use of SCUBA and surface supplied air while taking abalone in northern California establishes a refuge by depth because free divers generally cannot dive deeper than 8.4 m (28ft). The restriction to a specialized abalone iron for abalone take aid in protecting the soft and vulnerable foot and reducing incidental mortality.

Size Limits

The current minimum size is 178 mm (7 inches). Size limits are used to protect spawning stock of red abalone. Fishery models have been used to explore a range of size limits. A yield-per-recruit model was used by Tegner et al. (1989) to evaluate size limits; based on this study, the current sport size limit is reasonable.

Area Closures

Other than established reserve areas (such as the reserves at Point Cabrillo and Bodega Bay), local areas have not been closed to abalone fishing. However, area closures are necessary to respond to localized depletion before stocks fall below minimum viable levels. Failure to close fished down areas can lead to localized extirpation of abalone (Karpov et al. 2000).

Seasonal Closure

The abalone season is currently closed between December and March, and in July. Seasonal closures (or openings) may be used to reduce (or increase) take. Seasonal closures could also be used to protect red abalone during spawning periods (Section 4: Refinements of the Proposed Plan and Alternative Management Strategies).

Daily Limits

The current daily limit is 3 abalone per fisherman. Daily limits reduce the overall catch and protect local high use areas from being over fished. Daily limits are necessary in addition to annual limits because they are easier to enforce and because alterations in daily limits allow for more substantial changes in the total catch.

Annual Limits and Report Card

An annual limit is currently set at a maximum of 24 abalone per fisherman. Fishermen are required to record the number of abalone taken and take location on an abalone report card. Annual limits are used in combination with daily limits to limit the overall catch. Mandatory abalone report cards in the 2002 fishing year will be used to determine if the TAC is being met.

4. Refinements of the Proposed Plan and Alternative Management Strategies

The adaptive management approach for the red abalone fishery in northern California will be improved as new information is incorporated into the decision-making process. There is a need to move from a data-poor to a data-moderate scenario. The assessment criteria will be reviewed and refined along with other factors that may affect the stocks; thus, the proposed criteria target levels may change as better data becomes available through additional research and modeling.

With a moderate increase in the number of subtidal index stations and a telephone survey to verify the report card data, the proposed management strategy could remain the most cost-effective approach for the foreseeable future, as it uses data from diverse sources. However, this strategy relies heavily on relative measures of abundance (such as density and size frequency). Adjustments to the TAC are scientists' best estimates at sustainable fishing levels, grossly based on changes in criteria (Table 3 and 4) and relying on the limited, but best available data. With the development of additional data, future management strategies may encompass direct estimates of abalone abundance. By incorporating such estimates, changes in TAC could be directly linked to fluctuations in population size. In order to achieve these direct estimates, fishery parameters such as growth and mortality rates will need to be improved.

Future management may also incorporate additional catch restriction tools. However, management based on harvest rate control alone may not ultimately prove effective in protecting stocks from collapse. Marine protected areas may therefore be incorporated into future management as additional stock protection insurance.

This section describes: 1) new criteria that may be incorporated into the proposed management plan, 2) marine protected areas as insurance against stock collapse, 3) an alternative management strategy which links TAC to direct abundance estimates, and 4) additional management tools for possible future implementation. Any changes in either criteria or management approach will be implemented bi-annually with an option for emergency action once a year.

4.1 Potential New Criteria

Additional criteria may be added to aid in the management of the red abalone resource that will take into account abalone aggregation size and the spatial variation in abalone productivity. Aggregation indices or patchiness factors are useful in examining the effect of density dependent mechanisms on abalone behavior and reproduction (Allee effect), and on catchability (Post et al. 2002). Since fertilization success depends on adequate densities of abalone, maintenance of these aggregations may be important in ensuring sufficient larval production and successful recruitment.

4.2 Marine Protected Areas

There is an ongoing effort to establish marine protected areas (MPAs) as part of the Marine Life Protection Act (MLPA). The MLPA mandates the establishment of a network of no-take marine reserves in California. Deep water abalone stocks are currently protected by the restriction on the use of underwater air supply. Additional shallow water protected areas could be beneficial for red abalone in northern California to: 1) protect against population collapse in the face of ocean climate changes, demographic variability or management failure, 2) to provide areas in which to measure changes in red abalone populations unrelated to fishing effort such as environmental impacts, and 3) to protect essential juvenile abalone habitat in shallow water mandated under the federal Magnuson-Stevens Act. Shallow water MPAs in abalone habitat may become increasingly important if the current trend of deep water stock decline continues.

As part of the ARMP, the abalone team will work within the established MPA process to ensure that shallow water abalone habitat is included among areas for protection. Currently, approximately 14% of the red abalone population is protected in deep water. Protecting an additional 15% of the stock in optimal shallow water habitat (<8 m) with good densities of red abalone could provide important additional insurance against stock collapse. To achieve this target, 15% of abalone habitat in northern California will be considered for inclusion in MPAs. If the 15% habitat target is met by the ongoing MLPA process, no further action will be needed. Because of the loss of fishing area with the creation of MPAs, there is a potential for increased effort in remaining open areas. As MPAs are established, the overall fishery TAC will be reduced accordingly.

4.3 Alternative Management Strategy using Direct Biomass Estimates

Determination of the TAC as proposed in this plan is empirically based on density estimates and it is apparent that the fishing mortality rate at minimum viable density should be zero. However, we cannot at the present describe a direct relationship between density and catch rate. As additional research and modeling is completed, a direct relationship between density and TAC may be established, and resulting changes in criteria and / or TAC will be incorporated into the proposed management plan.

Simplified surplus production models that rely on estimates of abundance have been used in other benthic invertebrate fisheries to calculate TAC (Caddy 1986). In the Alaskan sea cucumber fishery, for example, fishery take levels are set at 5% of the estimated biomass per year (Woodby et al. 1993). Future management strategies for abalone may encompass direct estimates of abundance. Changes in TAC can then be linked to fluctuations in population size.

Determining TAC from Direct Estimates of Abundance

The simplest determination on TAC in relation to abundance relies on the concept of: 1) estimating population abundance and the natural mortality rate, and then 2) allocating a fraction of the population that would die of natural causes to the fishery in the form of a TAC using a surplus production model. In data-poor to -moderate situations, such calculations involve several assumptions including: a stable age distribution, no immigration or emigration, and non-age-specific mortality.

In order to determine TAC using direct abundance estimates, at a minimum, estimates of the natural mortality rate and abundance are needed. Limited estimates of red abalone natural mortality were made (primarily in the 1970's) for stocks in a few discrete locations in northern and southern California on the basis of tagging data. It will be necessary to update this information over a wider area in order to improve abundance estimates.

A key component of abundance methods is a reliable estimate of the habitat area of the target organism. The most desirable scenario would be to have accurate maps of the entire north coast intertidal and subtidal zones down to the deepest extent of abalone habitat. Obviously, this is an expensive undertaking with a long time frame. In the absence of accurate mapping, we propose using a simpler, less accurate interim method using existing habitat information that has been used by researchers and managers in other fisheries. A simple estimate of habitat area can be calculated by assuming that most of the nearshore coastline (excluding extensive sand dune areas and steep-cliff, high erosion areas) is abalone habitat. The resulting shoreline estimate forms the length of a polygon whose width can be estimated based on the known depth distribution of red abalone. This then would provide a crude, two-dimensional estimate of abalone habitat. Alternatively, the areal extent of canopy-forming kelps, primarily *Nereocystis luetkeana*, in northern California can be used as a proxy for rocky reef habitat. Red abalone are usually found in association with *Nereocystis*, though they can be found in rocky habitat devoid of canopy forming kelps such as around Bodega Head in Sonoma County and in the intertidal zone. Areal extent of kelp canopy can be used as a conservative lower bound estimate of suitable abalone habitat (Table 5).

Abundance can be simply determined using the formula $N = A * D$, where N= number of red abalone, A = area in sq. meters and D = red abalone density as number per meter square. More precise abundance estimates can be calculated from stratified area and density information. Confidence intervals are typically calculated based upon the variance associated with the density estimates. We plan to use a stratified approach in estimating abundance. Once the abundance estimate is derived, total allowable catch for the northern California red abalone fishery can be calculated using a simple surplus production model whereby: $TAC = CF * M * A$, where *CF* is a correction factor for data uncertainty which can range from 0.2 to 0.4, M is the instantaneous rate of natural mortality, and A is the abundance estimate for the area.

4.4 Additional Management Tools

In the future, additional seasonal closure may be considered to protect stocks. For example, if the timing of red abalone spawning is definitely determined, seasonal closures during spawning season may be warranted. The Department is carrying out a sampling program to measure the reproductive condition of animals caught in the recreational fishery during different times of the year.

Other tools need to be considered to reduce incidental mortality and improve enforcement effectiveness.

5. Focus questions for workshop

Proposed management approach

What is your general reaction to the proposed management approach? Will it result in a sustainable fishery?

Criteria:

Will these criteria assist the Department in determining fishery adjustments?

What is the best proxy for good recruitment: emergent or invasive densities, or a combination of both?

Is it reasonable to use average densities from emergent surveys at three index sites as the sustainable population density target in northern California?

What measurable criteria could be used for El Niño events and poaching?

Are the definitions of minor and major disease events logical?

Are there additional criteria that the Department should consider?

Fishery Adjustments: TAC changes and area closures

Are the options presented in the decision tables logical?

Do the specified sets of criteria warrant the actions listed?

Do the listed actions provide adequate management alternatives?

Alternative management strategies and refinements of the proposed approach

Is the alternative management strategy proposed an improvement on our proposed management plan?

Are there any additional alternative strategies or tools that should be considered in the management approach?

6. References

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